

FAR-ULTRAVIOLET IMAGING OF THE LARGE MAGELLANIC CLOUD POPULOUS CLUSTER NGC 1978 WITH WFPC2<sup>1</sup>

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## ABSTRACT

We have imaged the  $\sim 2.2$  billion-year-old Large Magellanic Cloud populous cluster NGC 1978 in the far-ultraviolet and visible with the second Wide Field/Planetary Camera (WFPC2) on the *Hubble Space Telescope*. The far-ultraviolet images show a sparse stellar field with little apparent density enhancement in the cluster core. The visible images are dominated by the cluster's first-ascent and second-ascent red giants, which are completely invisible to the far-ultraviolet filter. No evidence for a hot horizontal branch population of core-helium-burning stars is seen; nor is there any apparent indication of a significant blue straggler population. These results suggest that the presence of a rich, young population of field stars in the NGC 1978 region is responsible for the unusual location of the cluster in the integrated light color-color plots produced by *IUE*. © 1997 American Astronomical Society. [S0004-6256(97)02111-0]

## 1. INTRODUCTION

The origin of the far-ultraviolet excess (UVX) seen in E galaxies and spiral bulges is likely to be found in the late stages of evolution of low- and intermediate-mass stars (e.g., Dorman *et al.* 1995). The post-main-sequence evolution of these stars can be strongly affected by stellar interactions in dense star clusters (see Baily 1995 for a review). A good probe of the contributors to the UVX is the study of hot stars in UV-bright clusters; Watson *et al.* (1994) and Mould *et al.* (1996) reported on the first results of WFPC2 imaging of Galactic globular clusters for this purpose. The Magellanic Clouds harbor many clusters which are thought to be younger analogs to the Milky Way globulars and so whose

observation samples a complementary region of the cluster age-metallicity plane.

In this paper, we describe the far-ultraviolet and optical imaging of the populous Large Magellanic Cloud (LMC) star cluster NGC 1978 with WFPC2. NGC 1978 is a well-studied cluster which lies North of the optical bar of the LMC, near Shapley Constellation III and seen in projection against the LMC 4 supergiant shell (Meaburn 1980). The cluster has an apparent magnitude  $V=10.70$  and optical color  $B-V=0.78$  (van den Bergh 1981). Working in integrated light, Searle *et al.* (1980) assigned it to their Class VI, corresponding to ages between  $10^9$  and  $10^{10}$  years (Elson & Fall 1985). Optical color-magnitude diagrams of NGC 1978 show the cluster to possess a strong red giant branch and clump of core-helium-burning stars. An early indication of the cluster's intermediate age was the detection of carbon stars (Aaronson & Mould 1980, Lloyd Evans 1980) among the 22 AGB stars (Frogel *et al.* 1990). Isochrone fits indicate an age of  $2.2 \pm 0.2$  Gyr (Olszewski 1984; Bomans *et al.* 1995). The latter paper makes particular note of the strong degree of field star contamination along the line of sight towards NGC 1978 and gives an estimate of  $1.5 \times 10^8$  yr for the age of the most recent major epoch of star formation in the nearby field.

NGC 1978 was observed by *IUE* (deBoer 1981) with that satellite's  $10'' \times 20''$  aperture, much smaller than the full extent of the cluster. The *IUE* short wavelength (1550 Å) data suffered from poor signal-to-noise, and its radial extent did not seem to correlate well with that of the longer wavelength light (Cassatella *et al.* 1987). In the calibration by Barbero *et al.* (1990), NGC 1978 was found to be over a magnitude brighter at 1550 Å than expected for a 2 Gyr cluster, but a magnitude fainter than the metal-poor, blue horizontal branch clusters. Barbero *et al.* (1990) were unable to draw

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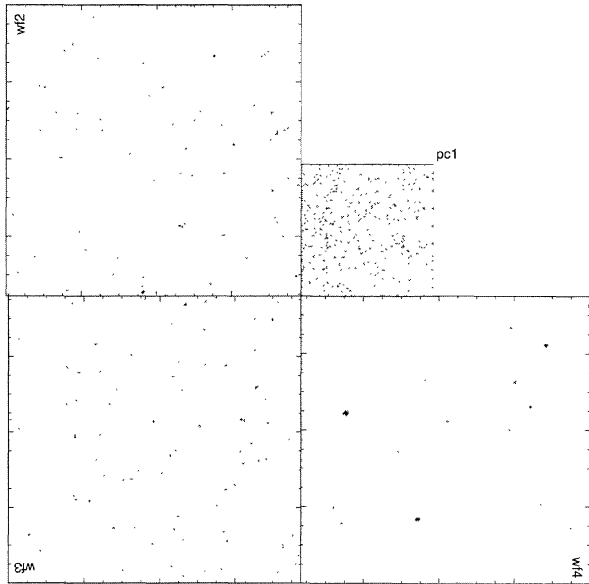


FIG. 1. The  $2 \times 2000$  sec, cosmic ray cleaned F160BW image of NGC 1978. The full width of the image is  $2.8''$ ; North is  $127^\circ$  clockwise from vertical, East is to the upper right. Note the effect that the filter vignette pattern has had on the corners of the three WF chips. The PC chip is centered on the cluster core, at  $\alpha = 05^h 28^m 44^s.6$ ,  $\delta = -66^\circ 14' 07''.5$  (J2000). Each chip is marked off in 50- and 200-pixel intervals corresponding to the star locations given in Table 1.

any firm conclusion regarding the origin of the UVX of NGC 1978.

## 2. DATA

### 2.1 Observations, Reductions, Calibrations, and Photometry

Two 1200- and two 800-second exposures in F160BW and two 10- and two 100-second exposures in F555W were taken on 1995 March 5 and 6. F160BW is a redleak-free wideband filter which has a low-throughput response from  $1300\text{--}1900\text{ \AA}$ . The properties of the F160BW filter are addressed in detail in Watson *et al.* (1994). F555W is the WFPC2 filter which most closely approximates Johnson V. WFPC2 and its filter set are described in full detail by Trauger *et al.* (1994) and Biretta *et al.* (1996).

The images were reduced in the standard pipeline (Holtzman *et al.* 1995a); they were then combined and cleaned of cosmic rays within NOAO's Image Reduction and Analysis Facility (IRAF). The combined F160BW image is shown in Fig. 1; Fig. 2 shows the F555W image. Comparison of the two figures serves to emphasize the extremely effective red-blocking ability of the F160BW filter, in which detection of even the brightest AGB stars is impossible.

Stars were identified in the combined F160BW frame using routines in IRAF/DAOPHOT (Stetson 1987; Davis 1994), and checked against the individual exposures to prevent contamination by unremovable cosmic ray events. We estimate that we have recovered  $\geq 90\%$  of the stars brighter than  $m_{160} = 17.5$ , but that completeness drops below 50% by

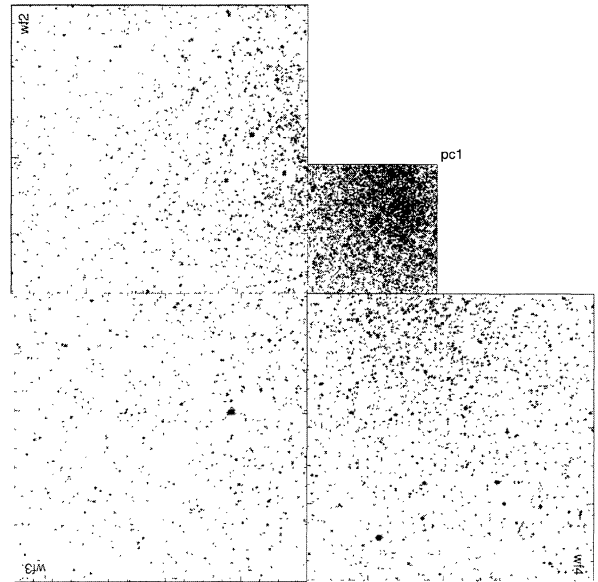


FIG. 2. The  $2 \times 110$  sec F555W image of NGC 1978. Image scale and orientation are as in Fig. 2. The image is dominated by red giants, which are absent from the FUV image, and by young field stars, which will dominate the UV-CMD.

$m_{160} \approx 18.5$ . Below  $m_{160} \approx 19.5$ , stars become indistinguishable from the background.

The identification process yielded 39 stars for which good photometry was obtainable in both filters. Following the procedure of Holtzman *et al.* (1995b, hereafter H95), we performed aperture photometry on these stars using a  $0.5''$  aperture. The locations and magnitudes of these stars are given in Table 1; the ultraviolet color-magnitude diagram (UV-CMD) of NGC 1978, drawn from this table, is shown in Fig. 3.

All magnitudes are reported in the STMAG system (H95), defined such that an object with a flat spectrum  $F_\lambda = 3.63 \times 10^{-9} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ \AA}^{-1}$  will have  $m_{\text{STMAG}} = 0$  in all filters. In determining the zeropoint for this relation, several corrections must be made. For the F160BW images, the most important of these arises from the buildup of particulate contaminants on the CCD window. WFPC2 underwent a standard monthly decontamination on 1995 February 12, some 21.5 days prior to our observations. Correction for this effect, taking the contamination rates from H95, leads us to correct our  $m_{160}$  zeropoints by 0.30 mag. Because the correction for a suspected row-dependent charge transfer efficiency (CTE) effect is not well-modeled (see H95) and is much smaller than the contamination corrections, we have not applied a CTE correction.

As described in H95 and in Whitmore (1995), there are chip-to-chip variations in sensitivity due to differences in the effective gain ratios and in the effects of contamination. Therefore we have chosen to define the STMAG zeropoints independently for each chip, so that all tabulated magnitudes may be more easily converted to physical flux units. The adopted zeropoints for each chip and filter are given in Table 2. Systematic errors in the zeropoints, introduced during the pipeline processing and subsequent corrections, are likely to

TABLE 1. Identification chart and photometric results for 39 hot stars in or around NGC 1978. The location of each star is given in columns 2–4. Columns 5 and 6 give the F160BW magnitude and the (F160BW–F555W) color, and column 7 gives the random error in the color.

ID	Chip	X(pix)	Y(pix)	$m_{160}$	$m_{160-555}$	$\sigma_{160-555}$
1	1	452	363	18.81	0.24	1.70
2	1	72	474	17.34	–0.73	0.43
3	1	181	716	17.29	–1.66	0.43
4	2	327	32	16.55	–1.63	0.12
5	2	511	110	18.38	0.34	0.58
6	2	478	166	17.52	–0.23	0.28
7	2	666	253	15.43	–2.07	0.05
8	2	493	313	17.12	–1.55	0.19
9	2	346	340	16.67	–1.51	0.15
10	2	62	424	16.84	–1.54	0.15
11	2	49	441	14.29	–2.47	0.02
12	2	180	603	17.57	–0.75	0.27
13	2	127	766	16.71	–1.49	0.13
14	2	87	728	17.25	–1.12	0.21
15	2	123	353	18.59	1.15	0.64
16	2	284	336	18.16	0.55	0.48
17	2	606	67	16.88	–0.76	0.15
18	2	712	181	17.21	–0.27	0.20
19	3	448	39	16.65	–2.23	0.14
20	3	282	66	16.17	–1.78	0.09
21	3	333	73	14.98	–2.45	0.04
22	3	187	372	15.60	–2.12	0.06
23	3	225	469	17.74	–1.33	0.37
24	3	205	543	16.82	–1.34	0.16
25	3	587	587	15.07	–1.75	0.04
26	3	131	649	19.68	1.23	1.87
27	3	183	714	19.00	–0.17	1.08
28	4	109	151	16.73	–1.69	0.15
29	4	352	155	12.47	–3.74	0.01
30	4	111	163	17.66	–1.22	0.33
31	4	430	234	15.53	–1.11	0.05
32	4	454	291	17.04	–1.30	0.19
33	4	377	309	18.25	–2.02	0.57
34	4	629	345	13.30	–2.72	0.01
35	4	132	448	17.37	–1.79	0.24
36	4	129	589	16.31	–1.32	0.10
37	4	335	642	14.66	–2.50	0.03
38	4	176	679	14.33	–2.24	0.02
39	4	71	795	14.25	–3.24	0.02

be present at the  $\pm 0.08$  mag level in F555W, and at the  $\pm 0.15$  mag level in F160BW.

## 2.2 Reddening and Distance Modulus

The optical color excess towards NGC 1978 is taken to be  $E_{B-V} = 0.08 \pm 0.05$  mag, of which  $0.02 \pm 0.02$  mag is due to extinction within the LMC (Bomans *et al.* 1995, and references therein). H95 gives tabulated values of the extinction in F555W as a function of  $E_{B-V}$ , under the assumption of a standard extinction law and  $R_V = 3.1$  (Cardelli *et al.* 1989), for O6 V and K5 V stellar spectra.

Interstellar extinction is particularly severe in the ultraviolet, and will be strongly dependent on stellar spectral type. To calculate the extinction in F160BW we have used the program by Cole (see Cole *et al.* 1997) convolving the filter + system throughput curves from Biretta *et al.* (1996) with a series of Kurucz (1991) model atmospheres and extinction laws appropriate for the Galaxy (Cardelli *et al.* 1989) and the

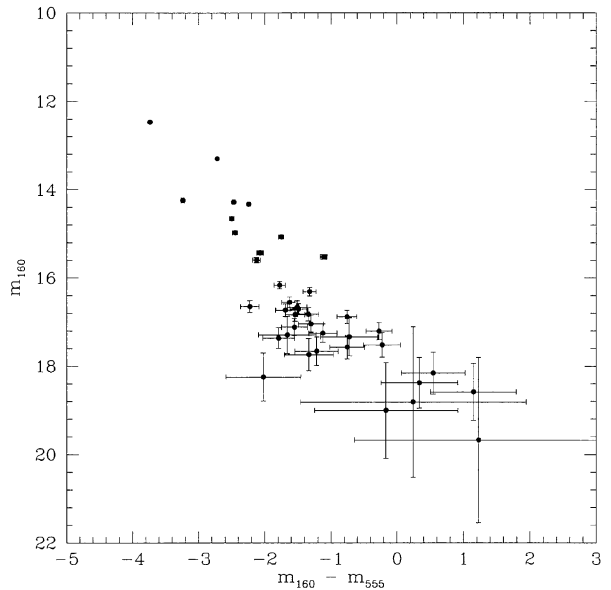


FIG. 3. Observed UV–CMD of NGC 1978. Error bars represent internal photometric errors. The cluster MSTO is not visible in this CMD; we expect it to be found at  $m_{160} \approx 22$ .

LMC (Howarth 1983). To verify the results we re-calculated the extinction in F555W using the parameters of H95 and found that our results differ from the H95 results by only  $+0.2\%$  for a K star, and by  $-0.3\%$  for an O star. Adopted extinction and reddening values as a function of  $E_{B-V}$  and stellar effective temperature are given in Table 3. Typical values of the extinction towards NGC 1978 will be  $\bar{A}_{160} = 0.72$ ,  $\bar{E}_{160-555} = 0.46$  for  $E_{B-V} = 0.08$ . The uncertainty in  $E_{B-V}$  will contribute a  $1\sigma$  (minimum) systematic error of  $\approx 0.18$  mag in  $M_{160}$  and  $\approx 0.06$  mag in  $M_{555}$ . If the reddening along the NGC 1978 line of sight does not follow a standard extinction law, these errors will be substantially increased.

We tied the  $M_{(160-555)_0}$  color to effective temperature by reconvolving the filter curves with model atmospheres in the zero-reddening case. Comparison to calibrations of the same filter set by Mould *et al.* (1996) and Watson *et al.* (1994) gave agreement to within  $\pm 5\%$ . We have adopted a true distance modulus to NGC 1978 of 18.5 mag (Panagia *et al.* 1991), corresponding to a distance of 50 kpc. The astrophysical UV-CMD constructed with this distance modulus and the extinction appropriate to each star is shown in Fig. 4. The derived effective temperature scale is given across the top of the figure. Sample error bars of  $\sigma_{160} = 0.25$  mag and  $\sigma_{160-555} = 0.28$  mag are indicated, representing the system-

TABLE 2. Adopted STAG zeropoints for each combination of filter  $i$  + CCD  $j$ , where  $STAG_{ij} = -2.5 \times \log(DN/s) - Zpt_{ij}$ .

Chip	$Zpt_{160}$	$Zpt_{555}$
PC1	13.395	20.948
WF2	13.270	20.939
WF3	13.270	20.937
WF4	13.270	20.965

TABLE 3. Extinction in the F160BW and F555W filters as a function of of  $E_{B-V}$  and Kurucz model atmosphere effective temperature, as determined using a Galactic+LMC reddening law.

$T_{\text{eff}}$ (K)	$R_{160}$	$R_{555}$	$E_{160-555}/E_{B-V}$
50,000	9.266	3.260	6.006
40,000	9.245	3.255	5.990
30,000	9.204	3.246	5.958
25,000	9.188	3.236	5.952
20,000	9.178	3.229	5.949
16,000	9.093	3.215	5.878
12,500	8.980	3.200	5.780
10,000	8.823	3.185	5.638
9,000	8.721	3.170	5.551
8,000	8.748	3.153	5.595
6,250	9.201	3.051	6.150

atic errors introduced by the pipeline processing and dereddening procedure.

### 3. THE ORIGIN OF THE *IUE* COLOR EXCESS: FIELD STARS, BLUE STRAGGLERS, OR POST-AGB STARS?

Since 1–3  $M_{\odot}$  stars spend their helium-burning lifetimes close to the red giant branch, and a negligible fraction of their total lifetimes in the hot post-AGB phase, the only significant contributors to the UV light of an intermediate-age cluster are stars at the top of the main sequence. Thus the UV color of a cluster is expected to be an accurate age indicator, and it was quite surprising when Barbero *et al.* (1990) found that NGC 1978 was more than 1 mag bluer in the *IUE* (1500 Å–3100 Å) color index than its  $\sim 2$  Gyr age would suggest.

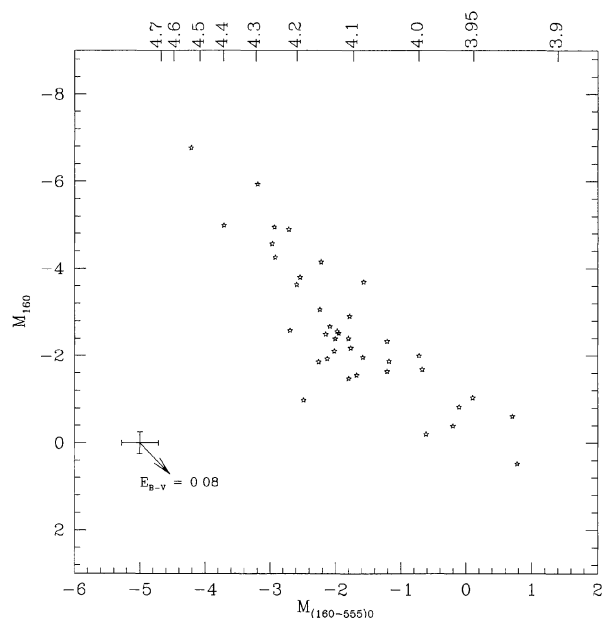


FIG. 4. Astrophysical UV–CMD of NGC 1978, for a reddening value of  $E_{B-V}=0.08$  and distance modulus  $(m-M)=18.5$ . The temperature scale is shown logarithmically at the top of the figure, and has been taken from the convolution of Kurucz model atmospheres and the appropriate filter throughput curves. A representative error bar showing systematic errors of  $\sigma_{160}=0.25$  mag, and  $\sigma_{160-555}=0.28$  mag is shown.

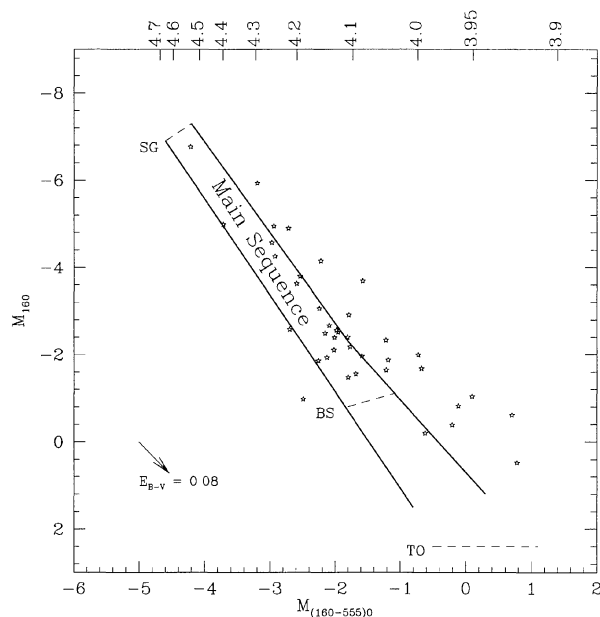


FIG. 5. As for Fig. 4, with the location of a theoretical main–sequence band for LMC metallicity shown (from Vassiliadis & Wood 1993). The dashed line marked *TO* indicates the expected location of the cluster main-sequence turnoff for an age of 2.2 Gyr. The line marked *BS* indicates the location of a star with twice the turnoff mass and hence gives an approximate indication of a cutoff in the blue straggler luminosity function. The line *SG* marks the predicted location of evolved, massive (20–25  $M_{\odot}$ ) field stars.

By placing a  $10'' \times 20''$  aperture on the cluster core, we simulated the *IUE* observation of NGC 1978. Comparing the WFPC2 F160BW magnitude to the *IUE* 1550 Å magnitude, we measured the cluster to be  $\sim 1$  mag fainter than reported by *IUE*; this result varied by more than a magnitude as we changed the location of our simulated *IUE* aperture. Our images are limited by the fact that the southern half of NGC 1978 has not been observed with WFPC2; whatever star or stars gave rise to the anomalous *IUE* measurements could therefore be excluded from our measurements. Slight offsets of the *IUE* aperture from the cluster core could have brought one of the UV-bright stars from Table 1 into the field of view, contributing substantially to the total 1550 Å light.

A simple model cluster comprising an A9–F0 main sequence together with a mid- to late-K RGB+AGB is predicted to have an integrated (160–555) color of roughly 3–3.5. This is 2–2.5 mag *bluer* than the observed color, but this difference is not meaningful. The discrepancy is due to the fact that the F160BW exposures were not deep enough to detect the diffuse FUV light from the stars at the cluster main-sequence turnoff.

We have transformed a set of points taken from the theoretical stellar evolutionary tracks of Vassiliadis & Wood (1993) for  $Z=0.008$  to the  $(M_{160}, (160-555)_0)$  plane by convolving the WFPC2 system response curves with the appropriately chosen Kurucz (1991) model atmospheres. These points are plotted as the zero-age and terminal-age main sequences in Fig. 5. These sequences are representative of the area within which most LMC main-sequence stars would be likely to be found in the (160–555) color-magnitude dia-



gram. Since most of the bright stars are probable field stars, a number of effects combine to scatter stars away from this area. Among these are (a) a range in distances, (b) unresolved binaries, (c) evolution of stars away from the main-sequence, or (d) a shallower than expected variation of the adopted extinction law with wavelength.

Three reference lines have been marked in Fig. 5: *TO* marks the predicted location of the cluster main-sequence turnoff ( $\approx 1.7 M_{\odot}$ ); *BS* marks a reasonable guess for the brightest potential cluster blue stragglers ( $\approx 3.4 M_{\odot}$ ); and *SG* marks the approximate location of a  $25 M_{\odot}$  main-sequence star or similar mass blue supergiant.

It can be seen from Fig. 5 that our observations were not sufficiently deep to reach the cluster main sequence. Figure 5 suggests that the UV color of NGC 1978 is primarily due to unevolved field stars and supergiants, although a contribution from blue stragglers in the cluster is possible.

We can test the contribution of field stars to our UV-CMDs by examining the radial distribution of hot stars with respect to the cluster center. We found that the average projected distance of our stars from the center of the cluster is  $\approx 1.1$ . There were no UV-bright stars within  $20''$  of the center of NGC 1978, and the bright stars ( $m_{160} \leq 16.3$ ) all fell more than  $1'$  from the cluster center. Comparison of Figs. 1 and 2 clearly shows the widely scattered distribution of hot stars relative to the optical light; this lack of correlation between the locations of the UV-bright stars and the overall distribution of cluster members indicates that field stars are indeed the primary contributors to the far-UV excess seen by *IUE*.

If blue stragglers (BSs) are produced by binary star mergers, the upper limit to their mass is  $2 \times M_{\text{MSTO}}$ . In NGC 1978, this yields  $M_{\text{BS}} \leq 3.4 M_{\odot}$ , corresponding to a spectral type later than B8–B9, and  $m_{160} \geq 18$ . The fainter stars in the cluster's UV-CMD (Fig. 3) could thus be accounted for. However, a common signature of cluster BS populations is a strong degree of central concentration (see Bailyn 1995), which is not in evidence here; 11 stars fainter than  $m_{160} = 17.5$  were found to be no more centrally concentrated than the more luminous stars. This is in marked contrast to NGC 1783, a cluster that is similar in mass and metallicity to NGC 1978, but which is a prolific producer of BSs (Cole *et al.* 1997). While NGC 1978 has produced but one UV-bright star (ID #1; see Table 1) within  $30''$  of its center, NGC 1783 exhibits no fewer than eleven BSs within its core radius of  $20''$ .

A possible explanation for our non-detection of a significant BS population in NGC 1978 is incompleteness of the photometric sample. NGC 1978 is roughly twice the age of NGC 1783, and its BSs should be correspondingly fainter: near or below our 50% detection threshold of  $m_{160} \approx 18.5$ . The incompleteness is expected to be most significant in the densest regions of the cluster; this effect prevented the discovery of BSs in several Galactic globular cluster cores (e.g., 47 Tuc; Paresce 1993) from ground-based observatories. The structural parameters of NGC 1783 and NGC 1978 have been investigated by, e.g., Mateo *et al.* (1991), and Elson (1992); although of lower total mass, NGC 1978 seems to be more centrally concentrated than the younger cluster. A com-

parison of Fig. 2 to the F336W image of NGC 1783 from Cole *et al.* (1997) gives a visual impression of this fact. It seems possible that we have been unable to recover the majority of NGC 1978's BSs from the central region of the cluster; because of the great difficulties associated with rigorous false star tests in the F160BW filter, we do not perform such a detailed analysis here.

If the BS production mechanisms in NGC 1978 have led to a BS population that is no bluer than the main-sequence turnoff, our detection rate would drop still further, as the F160BW filter rapidly loses sensitivity to stars cooler than  $\approx 10,000$  K. Monte Carlo simulations of BS production in open clusters (Pols & Marinus 1994), as well as evolutionary calculations of the products of stellar mergers (Sills *et al.* 1997) indicate that such "not particularly blue" stragglers can occur as a result of binary coalescence or stellar collisions. An alternate explanation of the apparent paucity of BSs in NGC 1978 is that the cluster simply lacks these objects. Until the relative importance of the various BS production mechanisms is fully known (see Bailyn 1995), we cannot quantitatively evaluate the likelihood of this explanation.

NGC 1978 is rich in AGB stars (Frogel *et al.* 1990); we might then expect from timing arguments (based on the models of Vassiliadis & Wood (1993, 1994)) to find that some of the cluster UVX derives from a hot post-AGB (P-AGB) star. Such a star would have  $12 \leq m_{160} \leq 14$  for  $\log T_{\text{eff}} = 4.5$ – $5.0$ , depending on whether the central object is burning hydrogen or helium, and on the distribution of any circumstellar ejecta. The brightest 2–3 stars in Figs. 3–5 may be considered candidate P-AGB stars; although their location along the theoretical main-sequence is somewhat suspicious, their luminosities place them well above the turnoff point of the dominant, 150 Myr field. Although models predict a P-AGB star in NGC 1978, the presence or absence of hot P-AGB stars in star clusters is a matter of small-number statistics, and we cannot say with certainty whether NGC 1978 contains any P-AGB stars. Bomans *et al.* (1995) detected several luminous, hot stars near NGC 1978, and concluded that they were most likely evolved, massive field stars. Our current data does not permit us to distinguish between the expected cluster P-AGB star and field BSGs in this region of the CMD; a spectroscopic investigation would be required in order to make this determination.

Recent evidence (see Dorman *et al.* 1995; Mould *et al.* 1996) points to hot horizontal branch stars as the origin of the UVX in old ( $\tau \gtrsim 10^{10}$  yr) clusters. Using the hot HB colors and magnitudes from Watson *et al.* (1994) and Mould *et al.* (1996), we find that the horizontal branch of NGC 1978 is expected to lie below  $m_{160} = 18.5$ . In fact, NGC 1978 is known from optical CMDs (Olszewski 1984; Bomans *et al.* 1995) to possess a very red helium-burning clump, a circumstance which effectively rules out the presence of a hot horizontal branch in any single-age population. In agreement with this point of view, we find no evidence for any hot-HB stars in NGC 1978; however, we note that such stars would lie just at our detection threshold in the F160BW filter. In any case, it seems apparent that the UVX of NGC 1978 does not share its astrophysical origin with that seen in true globular clusters.

## 4. SUMMARY

We have used far-ultraviolet and V-band imaging with WFPC2 to construct color-magnitude diagrams of the hot stars in NGC 1978. We discovered a substantial population of UV-bright stars above the main-sequence turnoff level of the 2.2 Gyr cluster, but which are not concentrated within the cluster core. Comparison of these stars to theoretical models suggests that most if not all of the UV-bright stars in the NGC 1978 line of sight are unevolved field stars; this finding is consistent with the interpretation of optical CMDs of the cluster (Bomans *et al.* 1995). We cannot entirely rule out the existence of one or more P-AGB stars or several blue stragglers in the cluster, but the hot stars show no discernible

overdensity relative to the general field population. We conclude that the UVX of NGC 1978 is not due to cluster members, but is attributable to the presence of a young population of field stars.

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## REFERENCES

- Aaronson, M., & Mould, J. R. 1980, *ApJ*, 240, 464  
 Bailyn, C. D. 1995, *ARA&A*, 33, 133  
 Barbero, J., Brocato, E., Cassatella, A., Castellani, V., & Geyer, E. H. 1990, *ApJ*, 351, 98  
 Biretta, J. A., *et al.* 1996, WFPC2 Inst. Hbk., v4.0 (STScI, Baltimore)  
 Bomans, D. J., Vallenari, A., & deBoer, K. S. 1995, *A&A*, 298, 427  
 Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, *ApJ*, 345, 245  
 Cassatella, A., Barbero, J., & Geyer, E. H. 1987, *ApJS*, 64, 83  
 Cole, A. A., Gallagher, J. S., Freedman, W. L., & Phelps, R. 1997, *AJ*, 113, 1700  
 Davis, L. E. 1994, A Reference Guide to the IRAF/DAOPHOT Package  
 deBoer, K. S. 1981, in *Astrophysical Parameters for Globular Clusters*, IAU Colloquium No. 68, edited by A. G. D. Philip and D. S. Hayes (Davis, Schenectady), p. 3  
 Dorman, B., O'Connell, R. W., & Rood, R. T. 1995, *ApJ*, 442, 105  
 Elson, R. A. W. 1992, *MNRAS*, 256, 515  
 Elson, R. A. W., & Fall, M. S. 1985, *ApJ*, 299, 211  
 Frogel, J. A., Mould, J. R., & Blanco, V. M. 1990, *ApJ*, 352, 96  
 Holtzman, J., *et al.* 1995a, *PASP*, 107, 156  
 Holtzman, J., *et al.* 1995b, *PASP*, 107, 1065 (H95)  
 Howarth, I. D. 1983, *MNRAS*, 203, 301  
 Kurucz, R. L. 1991, in *Precision Photometry: Astrophysics of the Galaxy*, edited by A. G. D. Philip, A. R. Upgren and K. A. Janes (Davis, Schenectady), p. 27  
 Lloyd Evans, T. 1980, *MNRAS*, 193, 87  
 Mateo, M., Welch, D., & Fischer, P. 1991, in *The Magellanic Clouds*, IAU Symposium No. 148, edited by R. Haynes and D. Milne (Reidel, Dordrecht), p. 191  
 Meaburn, J. 1980, *MNRAS*, 192, 365  
 Mould, J., *et al.* 1996, *ApJ*, 461, 762  
 Olszewski, E. W. 1984, *ApJ*, 284, 108  
 Panagia, N., Gilmozzi, R., Macchetto, F. D., Adorf, H. M., & Kirshner, R. P. 1991, *ApJ*, 380, L23  
 Paresce, F. 1993, in *Blue Stragglers*, ASP Conf. Ser. 53, edited by R. E. Saffer (ASP, San Francisco), p. 30  
 Pols, O. R., & Marinus, M. 1994, *A&A*, 288, 475  
 Searle, L., Wilkinson, A., & Bagnuolo, W. 1980, *ApJ*, 239, 803  
 Sills, A., Lombardi, J. C., Bailyn, C. D., Demarque, P., Rasio, F. A., & Shapiro, S. L. 1997, *ApJ*, 487 (in press)  
 Stetson, P. 1987, *PASP*, 99, 191  
 Trauger, J. T., *et al.* 1994, *ApJ*, 435, L3  
 van den Bergh, S. 1981, *A&AS*, 46, 79  
 Vassiliadis, E., & Wood, P. R. 1993, *ApJ*, 413, 641  
 Vassiliadis, E., & Wood, P. R. 1994, *ApJS*, 92, 125  
 Watson, A. M., *et al.* 1994, *ApJ*, 435, L55  
 Whitmore, B. 1995, *Photometry With the WFPC2* (STScI, Baltimore)